Reply to the reviewer #2

Thank you very much for your helpful comments. Based on your comments, we have improved the manuscript.

General comments:

The authors present a policy-relevant study of changes in precipitation deficits and fire metrics in equatorial Asia (EA) during a 2015-like El Niño event and in a decadal average sense at 1.5_, 2_, and 3_C warming levels. Results are based on a factual counterfactual probabilistic event attribution approach in a MIROC5 AGCM large ensemble framework. The following questions are explored:

• Did historical climate change increase the probability of the 2015 event?

• How will probabilities of drought, fire and fire emissions change when a major El Niño event similar to the one in 2015 occurs in 1.5_C, 2.0_C, 3.0_C climate.

Authors find that historical anthropogenic forcing has increased the likelihood of a drier than-2015 El Niño-driven precipitation deficit in the EA from 2% to 9%. At 1.5_C of warming, a drier event is 82% likely to occur. At 2_C of warming, the probability of a drier event drops to 67% likely (for reasons that are not entirely clear) but increases to 93% at 3_C of warming. This increased risk of drier conditions during El Niño events has ramifications for burned area extent, CO2 and particulate emissions in the regions.

The paper could be a valuable addition to the current body of literature on extreme events in warmer climates and the figures presented are clear and easy to interpret. There is care taken to connect findings to policy considerations whenever possible, particularly possible underestimates of EA CO_2 emissions under climate change scenarios. However, the interesting findings would benefit from additional detail on the method, model experimental framework, relationships between relevant processes, and, most critically, on the value-add gained by using a 100-member large ensemble as opposed to 10-member ensembles. Addressing the specific comments below should more than adequately clarify and strengthen conclusions.

Thank you very much for the helpful comments. Please see the section below for our detailed responses to your specific comments.

Specific comments:

I recommend omitting the phrase: “the year” from the title.

Thank you. We changed the title to "Historical and future anthropogenic warming effects on droughts, fires and fire emissions of CO_2 and $PM_{2.5}$ in equatorial Asia when 2015-like El Niño events occur".

Abstract On what is the statement "caused" based on? [L14] What is the dry season in Equatorial Asia (i.e., in terms of months)? [L15] The acronym PM2.5 is not yet defined [L21]

Based on previous studies and the analyses of Figs. 1-3 (e.g., Fig. 3c shows the -0.89 correlation between the Nino3.4 SST and precipitation anomalies), we stated "caused", but this terms may be too strong. We rephrased it to "contributed to". [line 15]

The dry season is June-November. [line 16]

We define acronym PM2.5 in lines 23-24.

Introduction It would be helpful to explicitly define when EA dry season occurs: : : Is the EA region the same as the SEA SREX region? If not, the specific latitude and longitude boundaries should be given. [L32-34]

We define the EA dry season (June-November) in line 37. We apologize that the EA region shown in the original Fig. 1 was incorrect. Actually, we use the definition of the EA region of GFED4s. We show the EA region in Fig. 1g and explain it in the caption of Fig. 1 and line 37.

Could you explain the ENSO phenomenon and how and why it "enhanced severe drought" to help guide readers? How did the 2015 drought compare to other ENSO events? This can be done through an explanation of the relationship between Walker circulation and convection and by including relevant citations on how the 2015 event compares to other El Nino in terms of effect on EA climate. [L32-34]

We explain the relationships between the 2015 El Niño and drought in lines 36-44 and 139-145.

Is the whole EA region considered tropical peatland? Can that qualification be defined (i.e. what is tropical peatland) and can it be explained why the region is susceptible to biomass burning? [L33]

We have improved these sentences as follows: "Parts of the EA region are tropical peatlands that contain tremendous amounts of soil organic carbon (Page et al., 2011) and huge biomass

(Baccini et al., 2012, 2017; Saatchi et al., 2011). Coupled with anthropogenic land-use change (e.g., expansion of oil palm plantations on peatlands), the severe drought increased fire activities in forests and peatlands" [lines 45-47]

Can you elaborate more on the findings of Lestari et al. 2014? It will help readers understand how this new study extends the findings. [L43]
I also recommend the following edit: "We use a probabilistic event attribution approach similar to Lestari et al. (2014), but our results are based on 100-member large ensembles of the MIROC5 AGCM with and without anthropogenic warming as opposed to 10-member ensembles." Then, a statement should be made about why the large ensembles were necessary and important to use. Justifying and highlighting the importance of large ensembles is a key point, especially for a special journal edition dedicated to large ensembles. [L48-50]

We explain the probabilistic event attribution approach, the difference between Lestari et al. (2014) and the present study, and why 100 member ensembles are necessary in lines 54-95 and 263-266. Because the 10 member ensembles of Lestari et al. (2014) are too small to examine how historical climate changes affected the probability of extreme events, we use 100 member ensembles [lines 74-76].

Question 1: Did historical climate change increase the probability of the 2015 event? How is historical climate change defined? Is it with respect to a certain base period? How is "change" defined in the presence of natural variability? [L47]
Can you elaborate on the probabilistic event attribution approach used in this study? It will help readers who are not familiar with detection and attribution techniques understand the opportunities and limitations of these approaches. How were they used in these cited papers? What were some of the key findings? [L48-54]

Historical climate change increased the probability of the 2015 drought event. We explain more details of the event attribution approach in lines 59-78 and 146-159, which should help readers understand how we define "historical change". On the other hand, we shorten the text mentioning the previous event attribution papers to prevent the paragraph from being too long [lines 76-78].

Question 2/3: Could these two sections be combined into one section about risk at 1.5, 2.0, and 3.0_C warming? [L55]

We combine those paragraphs regarding the risks at 1.5, 2.0, and 3.0°C warming into one paragraph. [lines 79-95].

Just a small comment but can the connection between the initiation of the HAPPI project and the Paris agreement be smoothed out a little? Was the HAPPI project initiated in response to or to inform the Paris agreement? [L56-61]

The HAPPI project was initiated in response to the Paris agreement. [line 87]

In regards to "Although socio-economic factors (e.g., conversions of forest and peatlands to agriculture and plantations of oil palm) are also important for fire activities (Marlier et al., 2013, 2015; Kim et al., 2015), we only examine the effects of climate change in this study." Does this mean land-use change is not considered? What are the relevant "effects of climate change" on these events (i.e. warmer mean temperature, circulation changes, changes in ENSO?)

We rewrote those sentences to "Although conversions of forest and peatlands to agriculture and plantations of oil palm are also important factors for fire activities (Marlier et al., 2013, 2015; Kim et al., 2015), we do not examine effects of land use change in this study." [lines 104-105]

Empirical functions: Can you elaborate on your observational dataset choices? Why did you choose the reanalysis products you use? How are the enhanced fire fraction, fire CO_2 emissions and fire $PM_{2.5}$ emissions computed in the Global Fire Emissions Database?

ERA Interim reanalysis (ERA-I) data (Dee et al., 2011) are used for temperature and vertical circulation. GPCP is precipitation data that merge rain gauge stations, satellites, and sounding observations to estimate monthly rainfall on a 2.5-degree global grid from 1979 to present. Because these datasets have been used by an enormous number of atmospheric circulation studies, we also analyze these data. [lines 39-40]

By combining satellite information on fire activity and vegetation productivity, GFED4s provide monthly burned area, fire carbon and dry matter (DM) emissions. We can also compute aerosol emissions by multiplying DM by the provided factors. [lines 110-114]

Could a figure demonstrating the relationship between burned area, CO_2 emissions, and particulate emissions be included? Is there a linear relationship between burned area and emissions?

Supplementary Figure 1 shows the relationships between fires and fire emissions in the EA area of the GFED4s during 1997-2016. Clear linear relationships are shown. [line 114]

What are the empirical functions used for in this study?

We use the relationships in Figs. 2a-c as the empirical functions to estimate fire and emissions from the simulated precipitation. [lines 119-129 and 214-221]

Model simulations: Can you provide a further description of the MIROC5 AGCM? I.e. what is the horizontal resolution of the atmosphere? What observed SSTs specifically were used, particularly for the “natural" SST? How was the “long-term anthropogenic signal" defined and removed?

The MIROC5 AGCM has a 160 km horizontal resolution [line 132]. We used the HadISST data for the observed SST [lines 133-134]. We explain the long-term signal of SST and the Nat SST in lines 153-159.

Most importantly, what fire model is used? How is it related to the land surface state and coupled to the atmosphere? What triggers a fire in the model? How are CO_2 and $PM_{2:5}$ concentrations determined for a given event? [L103-121]

The MIROC5 model has no fire module. Therefore, we used the empirical functions of Fig. 2 to estimate fire and emissions from the simulated precipitation. [lines 128-129 and 214-221]

What are the “corresponding standard deviation values”? [L108]

Here, the observed $\triangle P$ and $\triangle\omega 500$ are divided by their own standard deviation values. The $\triangle P$ and $\triangle\omega 500$ of each ensemble member are also divided by their own standard deviation values. [lines 134-136]

Throughout the study, the descriptions of the figures are a little brief. In this case: "The precipitation and vertical motion anomalies are closely related to the Nino 3.4 SST (an index of El Niño Southern Oscillation) in the observations, and the MIROC5 model represents these relationships well (Figs. 3c-e).” How are they related (i.e., subsidence and reductions in rainfall during an El Niño)? What does “represent these relationships well" mean (i.e., significantly correlated with observations)? [L108-110]

We have improved the descriptions in lines 139-145:
"The precipitation and vertical motion anomalies are closely related to the Nino 3.4 SST (an index of El Niño Southern Oscillation) in the observations (correlations are -0.89 and 0.76, respectively) (Figs. 3c-d). There is also a high correlation value between $\triangle P$ and $\triangle\omega500$ (-0.87) (Fig. 3e). It is suggested that El Niño (La Niña) accompanies descending wind (ascending wind) in the EA area (Fig. 3d), leading to negative (positive) $\triangle P$ (Figs. 3e and 3c). The MIIROC5 model well represents these relationships between Niño 3.4, $\triangle P$ and $\triangle\omega500$ in the observations (Figs. 3c-e), i.e., the regression lines of MIROC5 in Figs. 3c-e are close to those in the observations."

How were "prescribed long-term warming anomalies in SST" defined? From Figure 4, I can see that there are spatial differences in warming, where do they come from?
These details are likely important to the overall interpretation of the results and it would benefit the reader not to have to search for methodological descriptions in other studies or elsewhere in the paper. [L125-126]

We explain more details of the experimental designs of future simulations and how to add the SST anomalies in Fig. 4 to the observed data in lines 79-95 and 160-188.

The colorbar seems to be saturated in the bottom panel of Figure 4 over much of the Northern hemisphere, could the scale be adjusted to accommodate the 3_C mean difference? Is there a difference between the respective Figure 5 top and middle panels?

We changed the color scale in Supplementary Fig. 2. Supplementary Fig. 4 shows the sea ice differences.

Could you detail how these results were reached using the cumulative density functions? Particularly, how did the use of large ensembles affect the results? Does the "chance of exceedance" change with fewer members? [L154-158]

To help readers understand our results, we add "2% (1-4%) in Nat to 9% (6-14%) in Hist", "(in the 1.5°C and 2.0°C runs)" and "(in the 3.0°C runs)" in lines 206, 211 and 213.

The large ensemble simulations enable us to estimate the probabilities of drought exceeding the observed value [line 204]. We cannot robustly examine the probabilities using only the 10 members (10 samples) of Lestari et al. (2014) [lines 74-75].

Can you comment on why the chance of precipitation reduction exceedance more probable in the 1.5_ scenario than the 2_ scenario? [L157]

We explain this in lines 195-203.

"2015 CO2 emission of Japan due to fossil fuel consumptions" is a missing a citation [L168-169]

We included this comparison because it was highlighted that the fire emissions of EA exceeded the fossil fuel emissions from Japan when the massive 2015 fire event occurred (e.g., Field et al. 2016). However, readers other than Japanese readers may be not interested in this comparison. Therefore, we have omitted this paragraph.

I am sorry I may have missed something, but what is the AIM/CGE model used for? Was it introduced in the methods section? [L179-180]

AIM/CGE is the one of integrated assessment models (economic models) that produced emissions data for the SSP scenarios of CMIP6. In this paragraph, we suggest that additional fire CO_2 emissions due to climate change should be considered in emission scenarios that are used for the next CMIP7 future projection experiments. We have improved this paragraph [lines 228-248].